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Decision Support System for the Sustainability Assessment of Critical Raw Materials in SMEs

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Abstract

Technology-oriented Small and Medium-sized Enterprises (SMEs) face the problem of shortage of crucial resources, as functional components may contain up to 40 elements. Therefore, the assessment of alternative raw materials is of growing importance for the discipline of strategic product design and procurement processes as a topic of Information Systems (IS) research. Aspects of sustainability consider both ecological and economic objectives. Methods to assess companies' sustainability regarding its raw material consumption are an essential precondition for resource efficiency. This work at hand develops a conceptual decision and IS integration model for the assessment of products based on their raw material composition and implements this model as a software prototype, following a design-science approach. Its application is demonstrated in a real case scenario. The application's results show the comprehensibility and transparency in evaluating products' sustainability and enables companies to compare different alternative products, from both an ecological and economic point of view.

1. Introduction

Modern technology has dramatically increased the number of materials essential for product design, resulting in up to 40 chemical elements contained within assembly groups [33]. Particularly, in energy systems sector alone, by now 23 elements are used as essential functional materials and are simultaneously confronted with some constrains of supply [40]. For these materials, the holistic concept of 'criticality' displays risks connected with supply risk, vulnerability to supply restriction and ecological risks [27]. Previous works in the field have identified different sets of indicators for raw material criticality and algorithms for a joint evaluation of the aspects of criticality [1, 6, 16, 25], also considering specific problems of functional materials [34].

For companies, consideration of the criticality of the raw materials contained in its major products can help limiting the risk of distinct economic and operational supply disruptions [4, 20]. SMEs similarly face this problem, taking initiative searching for solutions to adapt assessments in analogy to those previously outlined by other corporations [5, 28]. This SMEs' initiative exemplarily gets supported by the German Federal Environment Foundation in research projects.

Integrating sustainability-driven component selection models considering raw material criticality can be achieved through Decision Support Systems (DSS). For this, it is essential to connect inter- and intra-organizational information sources like operative Business Information Systems, databases and poly structured data (structured and unstructured data), emanating from manifold different sources. Our work aims to contribute a generic DSS concept for the conceptual integration of different criticality indicator data sources into an effective DSS for procurement and product design divisions to allow decision making considering all three dimensions of sustainability: economic, ecological and social aspects. The concept design in this work includes economic and ecological aspects, while the social dimension is currently under interdisciplinary research. In this context we focus on the following research questions:

- How can SMEs apply Decision Support Systems to systematically assess raw material risks?
- How could such a Decision Support System be designed?

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This article is organized as follows: Starting on the motivation (section 1), the second section provides an overview of existing DSS concerning enterprise resource management and raw material selection. The third section describes the research method used for the conceptual integration model. Thereafter, the article describes the building of the IT decision model design (section 4), which gets demonstrated by a real case scenario. The article is rounded up by a discussion of the demonstration (section 5) and a conclusion (section 6).

2. Background and related work

For the implementation of criticality-based decisions, suitable decision support structures have to be developed. Due to the lack of established semantic and technical concepts in this context the previously derived decision criteria cannot easily be included into enterprise resource planning systems. Therefore in this article the required concepts and data models will systematically be developed from an existing decision model design from own previous works.

2.1. Environmental Management Systems

The problem of information availability is typical in research about environmental management information systems (EMIS) [9], as an "organizational and technical system for the systematical gathering, processing and provision of environmentally relevant information in a company" [26]. EMIS concepts are a subdomain for DSS [9]. In science and practice there are approaches for EMIS, for both a holistic and inter-company reporting and for the preparation of an environmental information management [32]. An EMIS can be assigned to three different categories [32]: *Reporting and information systems* are used for external reporting, *ECO-Controlling Systems* are used for internal company decision making processes, *Production-related EMIS* provide information for the design of eco-efficient production processes.

Based on a literature study it was found that there are no existing EMIS suitable for raw material selection processes in enterprises [3]. Design and implementation of a specific EMIS to identify and evaluate raw materials in products and their components is still missing [3].

2.2. State of the art of criticality assessments

Criticality assessments for raw materials can be subject of scientific, economic or policy decision support. The dimensions of existing criticality assessments include the dimensions supply risk, impact of supply disruption and ecological risks. The studies by U.S. National Research Council [25], the European Commission [6] and the working group of Graedel et al. [16] so far have provided the most influential methodologies for raw material criticality assessments. The research field of raw material risk assessment, especially considering companies' specific situation is still a heterogeneous research field [1]. The studies include scientific journal articles and project reports from both private- and state-run institute projects. Overall, state of the art in raw material criticality assessment is a multidimensional indicator-based assessment targeting for the holistic consideration of risks connected with resource extraction, processing, sustainable use and disposal.

The indicators of the ecological dimension of the sustainable product selection implemented by the hereby presented DSS have been taken from the Life Cycle Impact Assessment (LCIA) method 'ReCiPe' [13]. The ReCiPe method is an impact assessment recommended by the European Commission [7]. From its methodology, the two Areas of Protection (AoPs) Human Health and Ecosystem Quality are hereby used as ecological criticality measurements.

As was previously identified in an extensive literature review by Teuteberg and Straßenburg [32], Environmental Management Information Systems (EMIS) do not yet fully answer the question, what reference models for risk evaluation in environmental management could look like. Integrating criticality analysis' methodology into the DSS processes could help filling this gap.

With the hereby proposed methodology of implementing a criticality-driven decision design model into DSS we tackle research questions both on the procurement and supplier level, as brought up by Watson et al. [37] for the contribution of IS to the creation of an ecologically sustainable society. Including the selection of components and raw materials based on their supply risk and environmental impacts into DSS can help filling the necessity of creating Information Systems that incorporate environmental costs into prices and contribute to a more sustainable society [38]. A functional integration of sustainable decision criteria into an operation DSS therefore could help overcoming the persistent underscoring of the potential of IS when it comes to promoting enterprise sustainability, as identified by Melleville [24].

3. Research Method

The developed research design structures the process of gaining knowledge [21]. The design of the artifact (artifacts are constructs, models, methods, or instantiations) is based on the design science methodology by Hevner et al. [19] as a recognized framework for Information Systems Research. For the selection of critical raw materials a DSS is designed as an IT-artifact. Design Science is inherently a prescription-driven and problem-solving paradigm which aims at rigorous formation of relevant artifacts to solve solutions for management problems [19]. In this conceptual framework of design science it is possible to represent the interplay between relevance, rigor, and the design of an artifact in a systematic manner. Therefore three closely related cycles (rigor cycle, design cycle, relevance cycle) have to be explained [18].

In the first step in a rigor manner by a literature review criteria for the evaluation of potentially critical products, components and their contained raw materials are derived in own previous studies. Also in this step the relevance of the indicators is secured by two evaluation cycles (workshops) with thirteen experts combined from different domains including company references. By this, the whole management problem is described and criteria identified from the literature review are stabilized. For the article at hand, AHP (Analytic Hierarchy Process) is used to evaluate the semantic decision model and to realize a manageable decision concept for companies [29].

In accordance to the design-cycle, the IT artifact design is modeled in the second step. This conceptual design, which builds on previous work in the concept on EMIS, is also discussed with business experts. This step structured the strategic information needs analysis for further action in Information Systems.

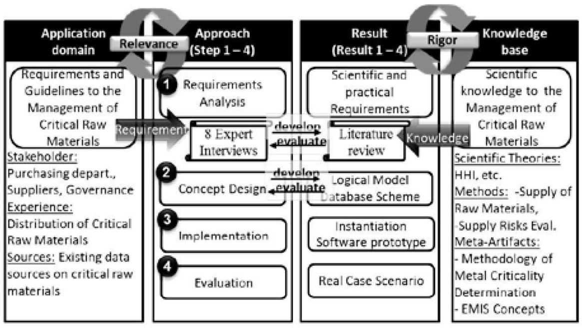


Figure 1. Research methodology for the criticality DSS in regard to Hevner et al. [19]

In the third step the conceptual model was developed as a first concept prototype. The implementation is evaluated by a typical real case scenario in the application domain (step 4). Fig. 1 shows the adapted research methodology in regard to Hevner et al. [19].

Subsequently in regard to the preliminary conceptual considerations, this prototype was developed incrementally in three steps, taking the requirements analysis into account (Figure 2).

For the modeling of requirements, semantic modeling tools are suitable. Different approaches in literature for the conceptional modelling of multidimensional information systems were discussed [11] Here Application Design for Processing Technologies (ADAPT) was used (action point 1). The logical data model is typically derived as a star schema (action point 2). For this purpose relational modeling methods are suitable. In the next step, the logical data model is translated into a database system language (action step 3). The setup of the physical database performs to accommodate the data. The model is implemented using the Business Information System software SpagoBI. For these innovative artifacts descriptive methods of evaluation should be used, because other forms of evaluation may not be feasible [19].

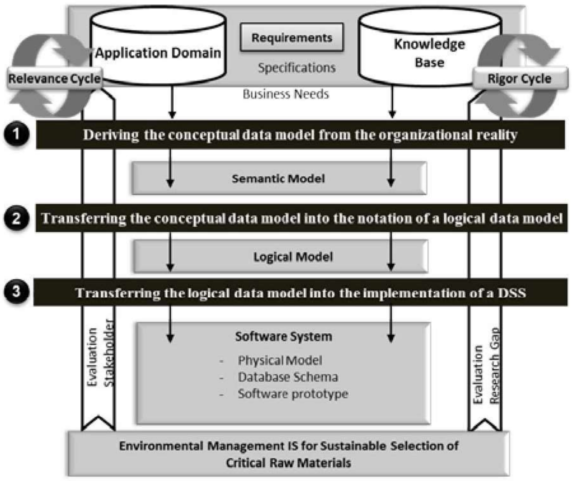


Figure 2. Applied conceptional data modeling procedure

Hevner et al. [19] further proposes to establish seven Guidelines (G1 to G7) for design artifacts to communicate the requirements, according to which the assumed methodology is described (Table 1).

Table 1. Seven Guidelines for design artifacts according to Hevner et al. [19]

#	Specification	Implementation in BI Design
1	**Artifact**	
	System-Design, implementation and instantiation	
2	**Relevance**	
	Relevance of critical raw materials, procurement problems in companies [4, 24]	
3	**Evaluation**	
	2-Step evaluation in regard to [19] (1) the implementation of the software prototype (2) by means of expert interviews and demonstration	
4	**Status quo**	
	Assessment of the status quo in the literature section based on own previous studies (see section 2)	

5	**Rigor**
	The development takes place in accordance with the methodological requirements for literature reviews, the design of IT artifacts and by means of software prototypes and interviews with experts for evaluation
6	**Design as a search process**
	Based on the requirements of science and practice, the reporting model was created in 3 iterations and perpetuated by 14 experts in procurement and management sciences.
7	**Dissemination**
	For scientists, a manageable framework for the assessment of critical raw materials can be shown. Companies will be demonstrated with a software prototype and in a real-case scenario, the feasibility of possible critical raw material evaluation From the technical point of view it has to be considered three steps how EMIS services to evaluate critical raw materials can be provided in the Decision Support System concept open source based.

4. Building the IT decision model design

Architecture planning is a decisive part of a DSS project. The planning allows statements about the decision model requirements, the number of participating systems and their interaction. Data flows are analyzed in regard to their technical and business perspective. Big data, global availability and a great amount of users [10] require this planning to be made in a holistic way. This section provides an overall view of the EMIS architecture to evaluate products and contained critical raw materials in a systematic manner with open source software.

Central modules of an Decision Support System for the strategic support of procurement and engineering functions may be built upon the basis of the architecture of an 'Environmental Management Information System Design to Assess the Availability of Critical Resources' [3]. This may be built upon the basis of the architecture of an EMIS 2.0, following Teuteberg and Straßenburg [32]. After the identification and the evaluation of raw materials it gets possible for enterprises to define various courses of action regarding the procurement and development of products. Following this approach, it is necessary to design an EMIS that allows the evaluation of raw materials.

4.1 Building the decision model

All measurements used in the Decision Support model of this article have been extracted from a broad literature study rigor cycle including 19 criticality studies. The indicators have been approved later on by an expert questionnaire and workshop rigor cycle including eight interdisciplinary experts. To determine a quantifiable indicator-based Strategic Design System considering a raw materials' criticality, we formulated a strategic decision model, which allows the measurement of raw material performance in both an economic and ecological dimensions.

Table 2. Indicators and data sources for the criticality criteria

Criteria	Indicator	Indicator Description	Measurement	Data Source
Concentration Risk	Country Concentration	Concentration of the annual production at country level, measured by Herfindahl-Hirschman Index	$\sum \text{Prod.Share}^2_{\text{Country}}$	USGS [36]
	Company Concentration	Concentration of the annual production at corporate level, measured by Herfindahl-Hirschman Index	$\sum \text{Prod.Share}^2_{\text{Company}}$	IntierraRMG [22]
Political Risk	Country Risk Political Stability	Political instability of producing countries, measured by Worldwide Governance Indicator 'Political Stability and Absence of Violence/Terrorism'	$\sum \text{Prod.Share}_{\text{Country}} \times \text{WGI-PV}_{\text{Cou}}$	USGS [36], World Bank [23]
	Country Risk Policy Potential	Ability of the producing countries to get new mining projects implemented, measured by the Policy Potential Index	$\sum \text{Prod.Share}_{\text{Country}} \times \text{PPI}_{\text{Country}}$	USGS [36], Fraser Institute [39]
	Country Risk Regulation	Ability of the producing countries to actually implement trade restrictions, due to their level of development, measured by the Human Development Index	$\sum \text{Prod.Share}_{\text{Country}} \times \text{HDI}_{\text{Country}}$	USGS [36], UNDP [35]
Supply Reduction Risk	Static Reach Reserves	Static reach of a raw material's reserves	$\frac{\text{Global Reserves}}{\text{Annual Production}}$	USGS [36]
	Static Reach Resources	Static reach of a raw material's resources	$\frac{\text{Global Resources}}{\text{Annual Production}}$	USGS [36]
	Recycling Rate	Recycling rate of a raw material, measured by current end-of-life recycling rate	End-of-Life-Recycling-Rate	UNEP [15]
Demand Increase Risk	Companion Metal Fraction	Share of the amount funded as a byproduct of the global production of a raw material	$\frac{\text{Annual Production as a By-Product}}{\text{Total Annual Production}}$	IntierraRMG [3, 22]
	Future Demand Technology	Estimated demand increase due to future technologies	$\frac{\text{Demand 2030 from Fut. Techn.}}{\text{Total Production 2006}}$	Angerer et al. [2]
	Substitutability	Substitutability of a raw material's function by a different raw material	Expert Estimation	Graedel et al. [17]
Human Health	ReCiPe Human Health	Impact of the ecological implications on Human Health	ReCiPe Endpoint Human Health LCIA	Ecoinvent LCIA Database [8]
Biodiversity	ReCiPe Ecosystem Quality	Impact of the ecological implications on Biodiversity	ReCiPe Endpoint Ecosystem Quality LCIA	Ecoinvent LCIA Database [8]

For the economic dimension we identified 27 indicator candidates from a literature research. With these possible indicators we conducted a survey involving five interdisciplinary experts in this field of research and asked them to rate each indicator's relevance using a six-point scale. We identified eleven remaining indicators to be applicable for companies to measure raw material performance within the economic dimension. Thereafter, we set up a workshop in an interdisciplinary group consisting of eight experts, including two in the field of Information Systems and two in the field of sustainability research to categorize the remaining 11 indicators. Hereby, we determined the four criteria: 'Concentration Risk', 'Political Risk', 'Supply Reduction Risk' and 'Demand Increase Risk'. The first concept 'Concentration Risk' addresses the risk of a raw material's production being concentrated on single countries and companies. The 'Political Risk' covers the risk of supply shortages according to the political stability of the mining countries, their ability to carry out new mining projects and their possibility to enforce trade restrictions. The third concept 'Supply Reduction Risk' is expressed by the ratio of the annual production both to the currently known reserves and resources as well as its worldwide end-of-life recycling rate. The indicators within the concept 'Demand Increase Risk' consider the companion metal fraction of a raw material, its increasing demand due to future technologies and its substitutability. With set and categorization of indicators, each resource's economic sustainability can be derived from a well-maintained data basis (see Table 2). Weighting of indicators is handled by applying an Analytical Hierarchy Process (AHP) [29].

The ecological dimension covers the concepts of 'Human Health' (six impact categories) and 'Ecosystem Quality' (nine impact categories), which are well established as Areas of Protection in the Life Cycle Analysis (LCA) community. Corresponding operational values are derived by the recommended ReCiPe Life Cycle Impact Assessment (LCIA) method.

The categorization for the economic and the ecological dimensions as well as a short indicator description can be seen in Table 2. The table also displays the calculation algorithm of each indicator as well as the required data sources providing information about the corresponding criticality aspect. The sources encompass publicly available reports, peer-reviewed research articles and commercially available data bases.

Thus, we formulated a (strategic) decision model to determine a raw materials' criticality from both an economic and ecological point of view, considering four and two criteria respectively, and consisting of 26 indicators altogether. The structure of the assessment model can be seen in Figure 3. For practical reasons, the implicit dependency of the higher-level measures of criticality dimensions and criteria from the indicator values will not be shown repititively in the data model figures later on.

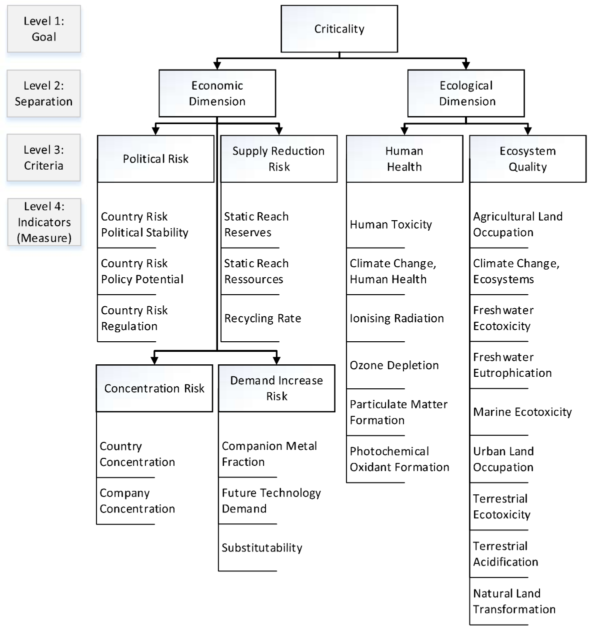


Figure 3. Decision Model Design for criticality-based selection processes

4.2 Conceptional Semantic data model

The basic sustainability dimensions, their hierarchy and measures are established for the evaluation of products and inherent critical raw materials in the previous section. The focus will now be on the conventional foundation to build the critical raw material decision support system. For this software concept we propose the specification of a DSS that summarizes all relevant information regarding the procurement and development of innovative products. Currently such information is not available in operative business information systems. Dedicated material master data sights (views) and indicators for the evaluation of products and raw materials are so far not existent in such systems [3]. In operative business information systems no information is available that allows decision makers to conduct a holistic assessment of materials criticality neither in the short-, nor mid-, nor long-term.

Conceptual models are designed to express user requirements of information systems in a formal and self-explanatory manner from a business user's point of view [12]. In this domain of DSS, we design a data model to translate user requirements and academic requirements into multidimensional data structures. Application Design for Analytical Processing (ADAPT) is one of the appropriate notations to express the model on a conceptual level [12].

As displayed in Figure 4, detailed information concerning the multidimensional data cube are considered. The main dimensions of the data cube are Time, Vendor, Product, Raw Material and Measure. As no criticality measurement is available more frequently than on an annual basis, an annual outline concerning the time dimension is sufficient for an applicable criticality determination.

Vendor-wise, a detailed outline from global, national and regional down to vendor-specific evaluation should be considered as a dimension in the multidimensional data cube. This allows for supply chain specific information about the sustainability evaluation.

The product-dimension includes outlines of the final distributed product and its consisting components. It can also include auxiliaries and supplies required for the production process.

The raw material dimension includes information about the chemical composition of each product, indicating a causal link between the two dimensions raw material and product. The chemical composition of a product or its components can be assessed from technical data sheets, life cycle and material data bases, ERP-systems, expert panels, laboratory investigation or supply chain analysis [3].

Finally, the measurement dimension includes all the criticality indicators and their respective meta-categories, both in the economic and the ecological dimension.

With this five-dimensional data model companies can quantitatively evaluate the procurement and product engineering dimensions of potentially critical products in their inherent raw materials.

4.3 Logical data model

The logical data model is the next step in the notation of a so-called conceptual data model. The logical data model is oriented to the physical storage of data. In the previous section, the functional specification lists all the definitions of the reporting requirements in detail, so that we are able to design the relational star scheme after finishing the document. The smallest unit to be analyzed is a product or a component of a product. For each product and its components the contained chemical ingredients may be displayed. This chemical composition is essential for the criticality determination.

Additionally, a characterization dimension is modeled in accordance to the semantic data model to analyze supplier hierarchies. For this application domain the inherent analysis dimensions were designed in such way that it is possible to re-use them for the over-all set of measures in economic and ecological areas. For implementation, the simplified star-model displayed in Figure 5 has to be split in accordance to the development of the technical system.

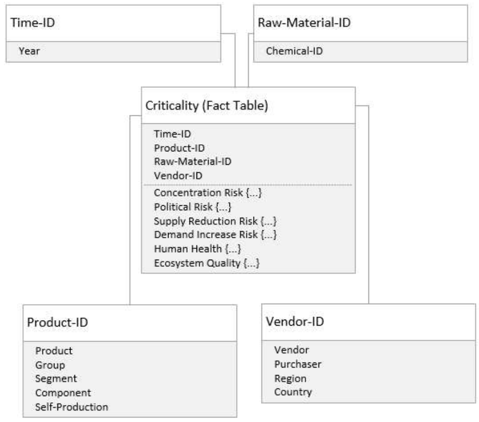


Figure 5. Logical data model

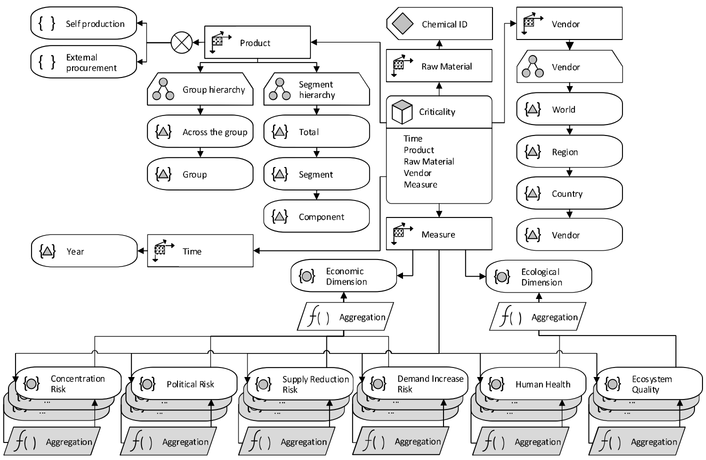


Figure 4. Semantic data model of the DSS

4.4 System implementation

In the third step the logical data model is transferred into the DSS against the reporting requirements. The prototype is based on several levels as shown in the Figure 6. In our case, the prototype is built in reference to the architecture of an EMIS 2.0 and can be described on a five-layer-architecture. In particular, the external data sources and presentation layer are identified as important components of the prototype [18] in this case.

On the one hand ERP systems or other enterprise systems can act as a data provider on the data source level in this EMIS-aligned concept. These systems provide data for the analysis of the procurement and product engineering task. On the other hand, external data sources, including open source data, proprietary databases and partially poly-structured data is used (see section 4.1, Table 2) [26]. All identified data sources use business intelligence-specific ETL processes (Extract, Transform and Load processes) from the MySQL database to load critical raw material information into the data warehouse of the DSS. The data storage, including the extraction and transformation processes, is developed by the open source software SpagoBI (Version 4.1, Release Candidate) [30]. The tool SpagoBI has been evaluated in several studies and was able to convince consistently in the studies carried out in the comparative analysis in terms of its technical design and the offered functionality [14, 31].

At the beginning we load products from the ERP system. In the second step, critical elements in reporting are displayed for a product in accordance with the reporting model.

The prototypical system design, which is simplified for the purpose of this article, is shown in Figure 6.

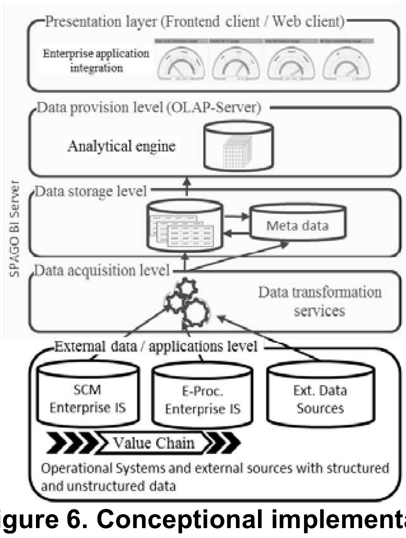


Figure 6. Conceptional implementation

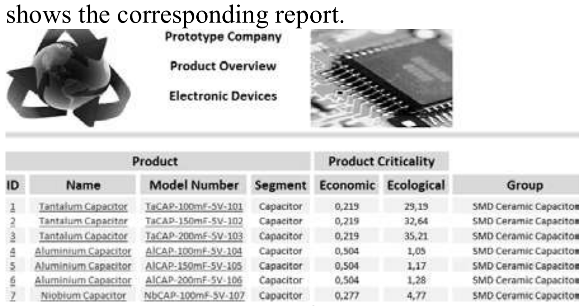
4.5 Demonstration

The evaluation is performed on a real case scenario to address all the relevant domain requirements in companies' decision making and is performed in an open source system. Hereby, the used evaluation system represents a fully developed enterprise decision model. The analyzed SME from the electronics industry is confronted with the task to assemble circuit boards with capacitors. These circuit boards have to be delivered sustainably, due to customer requirements. To achieve this, the available capacitors have to be evaluated concerning their economic and ecological sustainability. For this strategic task, an assessment of the contained raw materials is necessary, which cannot be accomplished with the existing enterprise resource planning systems. For this company, the evaluation of the raw materials was carried out according to the developed assessment process. The technical concept is therefore implemented in the SpagoBI system, offering the corporate structure and the data basis to accomplish extensive analyses to evaluate raw materials.

For the demonstration example, the raw material tantalum in capacitors is evaluated representatively for other elements.

At the beginning, different products are selected and loaded from the source systems (see section 4.2). These data were harmonized and consolidated for the decision support task (see Figure 6).

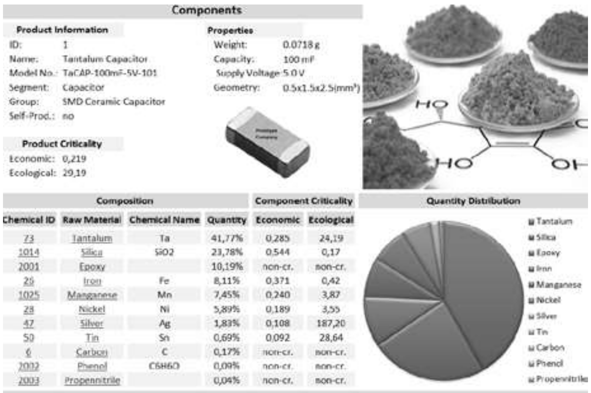
For the analysis task, it is necessary in a first step and in accordance to the semantic model to display all products within the relevant segment. Figure 7 shows the corresponding report.


Prototype Company
Product Overview
Electronic Devices

Product				Product Criticality		
ID	Name	Model Number	Segment	Economic	Ecological	Group
1	Tantalum Capacitor	TaCAP-100mF-5V-101	Capacitor	0,219	29,19	SMD Ceramic Capacito
2	Tantalum Capacitor	TaCAP-150mF-5V-102	Capacitor	0,219	32,64	SMD Ceramic Capacito
3	Tantalum Capacitor	TaCAP-200mF-5V-103	Capacitor	0,219	35,21	SMD Ceramic Capacito
4	Aluminium Capacitor	AlCAP-100mF-5V-104	Capacitor	0,504	1,05	SMD Ceramic Capacito
5	Aluminium Capacitor	AlCAP-150mF-5V-105	Capacitor	0,504	1,17	SMD Ceramic Capacito
6	Aluminium Capacitor	AlCAP-200mF-5V-106	Capacitor	0,504	1,28	SMD Ceramic Capacito
7	Niobium Capacitor	NbCAP-100mF-5V-107	Capacitor	0,277	4,77	SMD Ceramic Capacito

Figure 7. Excerpt of the product report within a segment

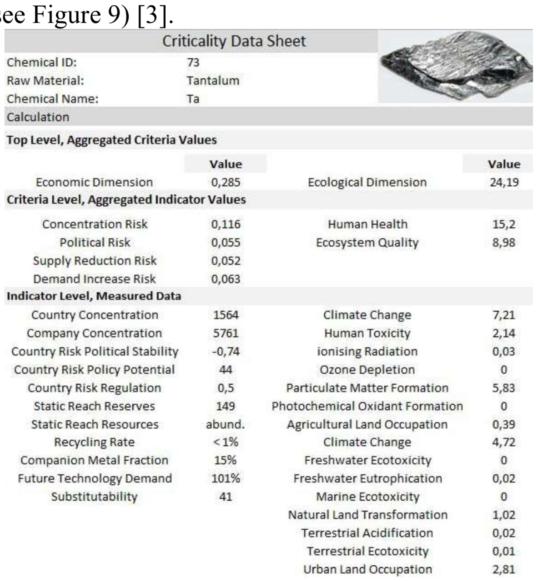
In the second step, the chemical composition of a chosen product is displayed, which is the composition of a tantalum capacitor in our demonstrated case (see Figure 8). This subdivision is essential for our DSS and is implemented as presented in the 'Raw Material' dimension within our ADAPT model.



Composition				Component Criticality	
Chemical ID	Raw Material	Chemical Name	Quantity	Economic	Ecological
73	Tantalum	Ta	41,77%	0,285	24,19
1014	Silica	SiO2	23,78%	0,544	0,17
2001	Epoxy		10,19%	non-cr.	non-cr.
26	Iron	Fe	8,11%	0,371	0,42
1025	Manganese	Mn	7,45%	0,240	3,87
28	Nickel	Ni	5,89%	0,189	3,55
47	Silver	Ag	1,83%	0,108	187,20
50	Tin	Sn	0,69%	0,092	28,64
6	Carbon	C	0,17%	non-cr.	non-cr.
2002	Phenol	C6H6O	0,09%	non-cr.	non-cr.
2003	Propennitrile		0,04%	non-cr.	non-cr.

Figure 8. Excerpt of the chemical composition report

In the third step, a single element can be selected, in this case tantalum. Detailed information about single raw material's criticality measures can be accessed in the corresponding report. This specific information can help the practitioner to identify individual action alternatives, e.g. long-term supplier contracts, physical storage, hedging, vertical integration or closed loop supply chain management (see Figure 9) [3].



Criticality Data Sheet			
Chemical ID:	73		
Raw Material:	Tantalum		
Chemical Name:	Ta		
Calculation			
Top Level, Aggregated Criteria Values			
	Value		**Value**
Economic Dimension	0,285	Ecological Dimension	24,19
Criteria Level, Aggregated Indicator Values			
Concentration Risk	0,116	Human Health	15,2
Political Risk	0,055	Ecosystem Quality	8,98
Supply Reduction Risk	0,052		
Demand Increase Risk	0,063		
Indicator Level, Measured Data			
Country Concentration	1564	Climate Change	7,21
Company Concentration	5761	Human Toxicity	2,14
Country Risk Political Stability	-0,74	Ionising Radiation	0,03
Country Risk Policy Potential	44	Ozone Depletion	0
Country Risk Regulation	0,5	Particulate Matter Formation	5,83
Static Reach Reserves	149	Photochemical Oxidant Formation	0
Static Reach Resources	abund.	Agricultural Land Occupation	0,39
Recycling Rate	< 1%	Climate Change	4,72
Companion Metal Fraction	15%	Freshwater Ecotoxicity	0
Future Technology Demand	101%	Freshwater Eutrophication	0,02
Substitutability	41	Marine Ecotoxicity	0
		Natural Land Transformation	1,02
		Terrestrial Acidification	0,02
		Terrestrial Ecotoxicity	0,01
		Urban Land Occupation	2,81

Figure 9. Excerpt of element criticality

Additionally, the historic development of criticality indicators can be assessed for functional raw materials, as displayed in Figure 10 for tantalum and manganese in the measurement of Static Reach Reserves. With this data analysis a company is able to better interpret current criticality data and display past changes.

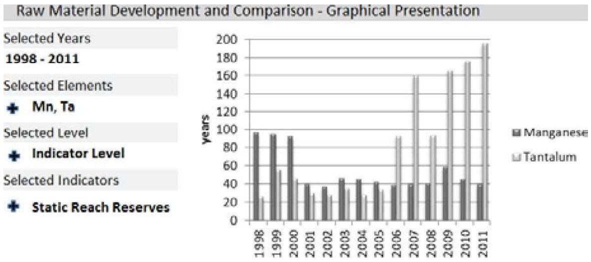


Figure 10. Exemplary report of historic criticality development

The evaluation of the DSS shows the feasibility of sustainability assessment for products in SMEs. On the one hand side, the real case scenario of tantalum shows that in this case the techno-economic availability concerning the static reach of reserves is less problematic. On the other hand, it can be seen that tantalum is considered critical due to the high company concentration and focus on instable mining countries as well as the high ecological impacts from climate change and particulate matter formation (see Figure 9 and Figure 10).

5. Discussion

In this work at hand we prototypically presented the first DSS enabling companies to evaluate the sustainability of their products and supply chain by considering the criticality of the raw materials at use. Consequently, our DSS in principle enables a company to increase its level of sustainability regarding its economic as well as ecological performance. Thereby, the prototypical DSS is based on current research results from both Information Systems research and sustainability research, measuring a raw material's criticality quantitatively and making this process applicable for companies.

As presented in the ADAPT raw material identification within different products is implemented in our software prototype. By this, a linkage between a raw material's criticality and product containing this resource is possible and visualizable.

The logical data model together with the system design builds the basis for the design of the prototypical implementation. This conceptual design helps companies to implement a DSS for the evaluation of its own products.

A deeper analysis of the assessment requires the company's knowledge about its products' ingredients on an elementary basis. Gathering this information can be a challenge for a company, especially for SMEs. The assessment results allow a more detailed discussion of the decision. The method helps to find a mutually acceptable solution and to evaluate possible tradeoffs. This result improves the comprehensibility and covers any inconsistencies in the decision-making. In addition to the already mentioned information sources, Supplier Self Assessments can be of help closing this knowledge gap with relatively low costs. First approaches have emerged in the automobile industry, but their applicability for other industries, especially for SMEs, is yet to be shown. Known value net approaches can help to couple large company databases dynamically.

The availability of criticality data on an annual basis is a limitation of the application case. Due to this update frequency, unexpected or short-term occurrences in politics or trade will not be covered by the proposed DSS. The influence of short-term occurrences on strategic criticality assessments, which aim for mid- and long-term evaluation of resource use is notable. This problem is known to the authors and was considered in the evaluation. The use of a more dynamic DSS for companies is open for further research, but it would require dynamic indicators and additional data basis.

6. Conclusion

This article shows for the first time how a functional criticality-based sustainability assessment can be implemented on a product level into an Environmental Management Information System (EMIS) concept via a DSS. The used indicator set for the multi-criteria decision aid (MCDA) was identified from a rigor- and relevance-cycle.

The article displayed the necessary and evaluated semantic data model for the user requirements which will allow companies to implement criticality criteria. This concept allows the extension of existing EMIS. The proposed system design shows exemplarily how enterprises can implement criticality-based sustainability analysis. A real case scenario for the prototypical DSS was successfully shown as evaluation method for the developed decision support model. The implementation of these DSS is essential for the problem class of resource efficiency in enterprises as a key to sustainable procurement and product design.

For future research, we are aiming for a real-data case study for an enterprise in order to continue the results of this study and raise its evaluation level. This can be achieved through Consortium Research projects, as recommended in Information Systems. Several tests concerning its practicability need to be run in cooperation with different companies, as the highest level of evaluation. Additionally, our software prototype's graphical user's interface could be adapted to present the necessary information more efficiently. Hereby, possible weaknesses within the implementation of our DSS will be identified.

7. References

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